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Satellite-Derived Moisture-Bogusing Profiles for the Northwest Pacific Ocean

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Forecast Guidance and Naval Systems Support Division
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ABSTRACT

A set of 12 vertical profiles of relative humidity versus pressure for use in satellite bogusing of moisture into numerical weather prediction initial analysis is presented for the Northwest Pacific Ocean region. The profiles are based on a subjective satellite image cloud classification scheme applied to a concurrent set of satellite images and upper-air soundings taken from ships. Vertical relative humidity profile composites and statistical significance tests are presented for each category.

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SATELLITE-DERIVED MOISTURE-BOGUSING PROFILES FOR THE NORTHWEST PACIFIC OCEAN

1. INTRODUCTION

Since the early 1970's the National Meteorological Center has attempted to improve its initialization of moisture in numerical weather prediction models by using a technique called "moisture bogusing", (Chu, 1977; Smigielski et al., 1982; Timchalk, 1986). The technique involves including pre-computed vertical profiles of relative humidity in model initialization over ocean areas normally devoid of in situ observations. Each moisture profile is intended to be representative of a particular meteorological condition identifiable by subjective satellite image analysis.

The Naval Oceanographic and Atmospheric Research Laboratory (NOARL) Atmospheric Directorate has funded investigations looking into the potential benefit of implementing a moisture bogusing program for the Navy's numerical weather prediction models (Lyons, 1986a; Lyons, 1986b; Eddington, 1989). This report is the second in a series of investigations funded by NOARL to determine moisture bogusing profiles for different ocean regions around the world. The first report (Eddington, 1989) presented results obtained from data taken over the North Atlantic Ocean. This report presents results from the Northwest Pacific Ocean. The report proceeds as follows: Section 2 describes the data and procedures, Section 3 describes the results, Section 4 contains a discussion, and Section 5 is a summary.

2. DATA AND PROCEDURES

Vertical moisture profile composites for the Northwest Pacific Ocean were determined by matching soundings of relative humidity versus pressure with visual and infrared satellite imagery taken from the GMS geostationary satellite. A total of 409 soundings, taken from ships in the Northwest Pacific Ocean during the years 1981-1987, were used in creating the composite moisture profiles. Figure 1 shows the locations of the ship soundings used in this study. Table 1 shows the number of soundings by month and by year.

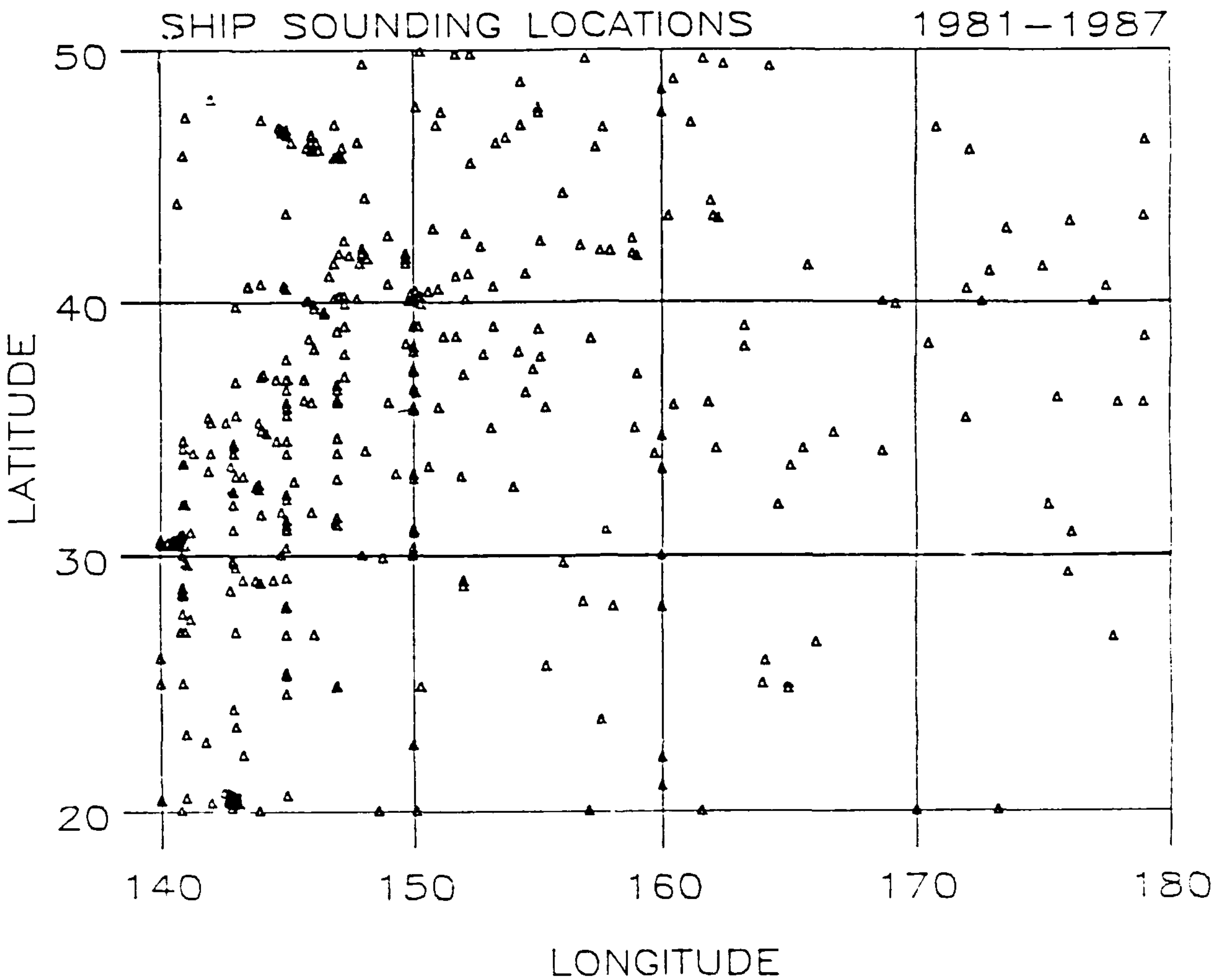

Fig. 1. Ship sounding locations.

Relative humidity values reported at mandatory and significant levels were interpolated to 16 pressure levels ranging from 1000 to 250 mb. All missing data above the highest reported value were set to 5 percent. All soundings used were within 1 hour of the satellite image time.

The cloud pattern categorization scheme used in this study is the same as that used in the North Atlantic study, and is presented in Table 2. Each sounding was assigned to one of the first 12 categories based on a subjective analysis of the corresponding satellite image(s). Composites and 67 percent confidence limits were computed for each category. Significance tests using the Wilcoxon rank-sum test were made to determine the statistical significance of each category's relative humidity profile when compared with the rest of the sample.

Table 1. Number of Soundings

	1981	1982	1983	1984	1985	1986	1987	Total
Jan	0	0	0	3	8	4	3	18
Feb	6	5	4	6	7	4	12	44
Mar	7	2	7	1	3	4	9	33
Apr	3	3	4	4	5	8	10	37
May	7	6	6	11	12	13	14	69
Jun	0	1	6	0	7	0	2	16
Jul	1	0	2	5	1	10	4	23
Aug	8	5	7	9	7	6	5	47
Sep	1	2	3	1	1	2	12	22
Oct	7	4	5	5	7	9	7	44
Nov	5	2	6	7	1	8	8	37
Dec	1	4	4	3	0	3	4	19
Total	46	34	54	55	59	71	90	409

3. RESULTS

Relative humidity profile composites for the 13 cloud pattern classification categories are presented in Table 3. The composites are also graphically presented in Figs. 2-14 with 67 percent confidence limits, and level by level significance values. The number of soundings in each category is given in the top right corner of the figures. The significance values represent the probability that the individual category versus the ensemble relative humidity rank-sum discrepancies was due to chance. The dashed line represents a significance value of 0.05. The smaller the significance value the more significant the difference between the category's soundings and the remaining soundings.

Table 2. Cloud pattern classification scheme.

Category #	Description
1	Clear
2	Stratus
3	Stratocumulus
4	Open-celled cumulus
5	Open-celled cumulonimbus
6	Altocumulus (chaotic)
7	Altostratus (organized)
8	Thin cirrus
9	Thick cirrus
10	Low, mid, and high clouds (chaotic)
11	Low, mid, and high clouds (organized)
12	Undecided
13	Ensemble

In all but three of the categories (categories 5, 11, and 12) at least 7 out of 16 levels had significance values of 0.05 or lower. The reason for the poor significance values in categories 5 and 11 is that these categories had only one sounding in their samples. Poor significance values were expected for category 12, it being the undecided category.

Significance values were also computed to determine the significance of one composite when compared to another composite. The results are presented in Table 4. Two values are given for each comparison. The first value is the significance value for the comparison as a whole (the average of the 16 levels). The second value (in parenthesis) is the number of pressure levels with a significance of 0.05 or lower.

Table 3. Relative humidity composite (%).

Pres. (mb)	Category												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1000	76	86	76	70	58	75	78	81	79	83	63	79	77
950	74	81	80	75	69	78	78	80	81	83	69	79	79
900	64	70	80	76	81	78	81	75	80	81	75	73	76
850	57	56	73	73	92	77	84	69	70	79	83	67	72
800	45	57	63	60	58	74	78	59	63	75	66	60	64
750	38	50	50	46	51	72	74	48	60	72	79	52	56
700	35	40	38	40	52	64	68	38	44	71	96	48	49
650	37	34	29	32	56	61	62	34	43	68	92	45	45
600	37	24	24	31	55	55	58	33	50	63	89	43	43
550	32	19	22	28	56	52	55	32	57	62	86	40	41
500	29	18	21	26	58	41	52	32	64	62	84	37	39
450	28	19	23	24	52	37	46	33	70	59	79	36	37
400	27	20	21	24	47	34	33	37	66	60	75	35	36
350	25	16	21	24	39	26	30	41	59	57	65	33	34
300	23	17	20	22	24	27	22	38	60	47	59	32	31
250	20	16	15	18	9	20	17	32	43	35	5	24	24

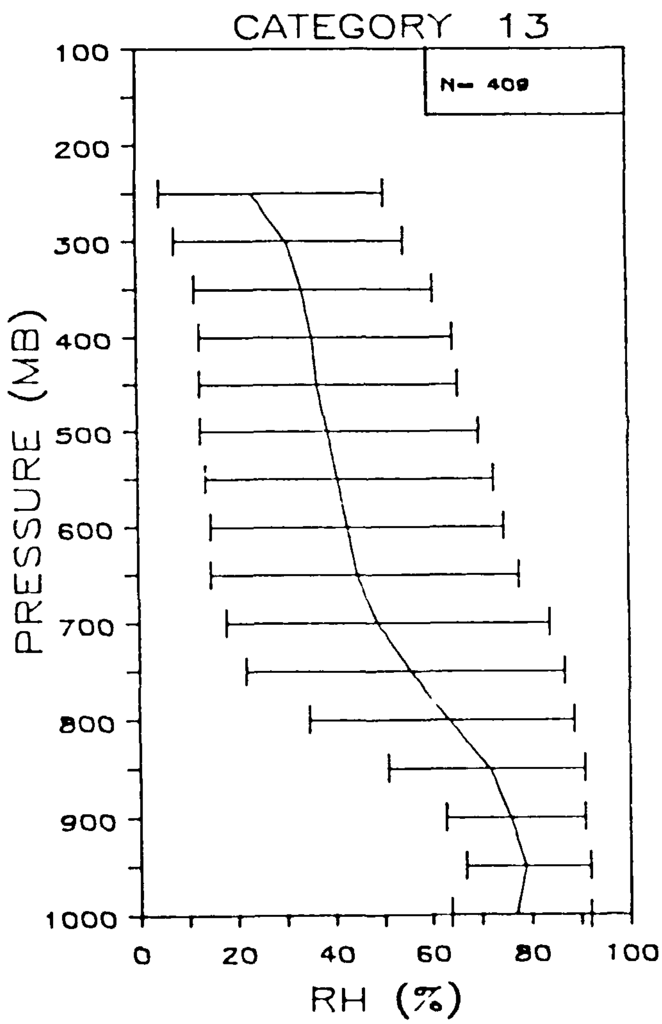

Fig. 2. Relative humidity composite with 67 percent confidence limits for Category 13 (sample ensemble).

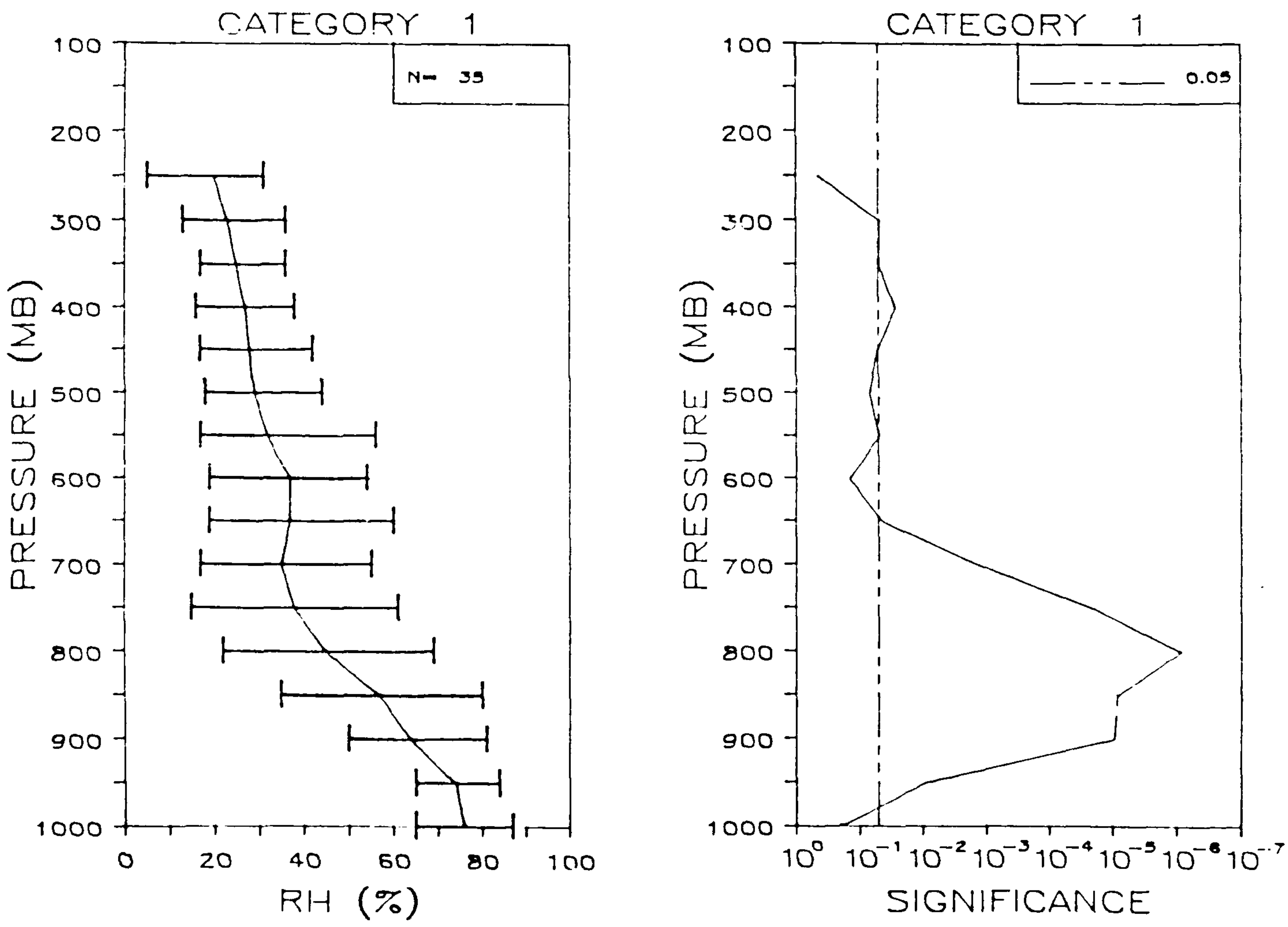

Fig. 3. Relative humidity composite with 67 percent confidence limits and level by level significance values for Category 1 (clear).

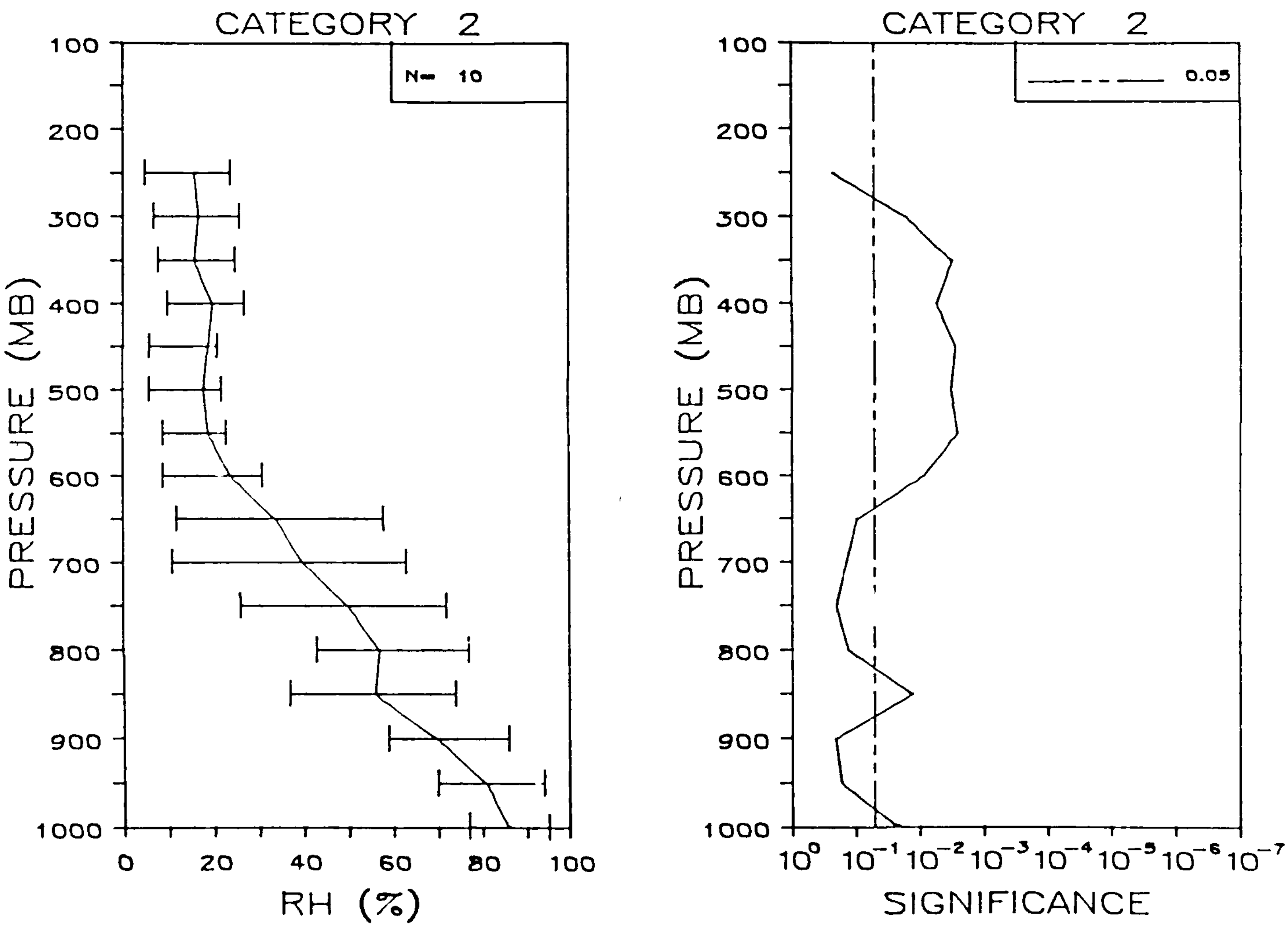

Fig. 4. Same as in Fig. 3 but for Category 2 (stratus).

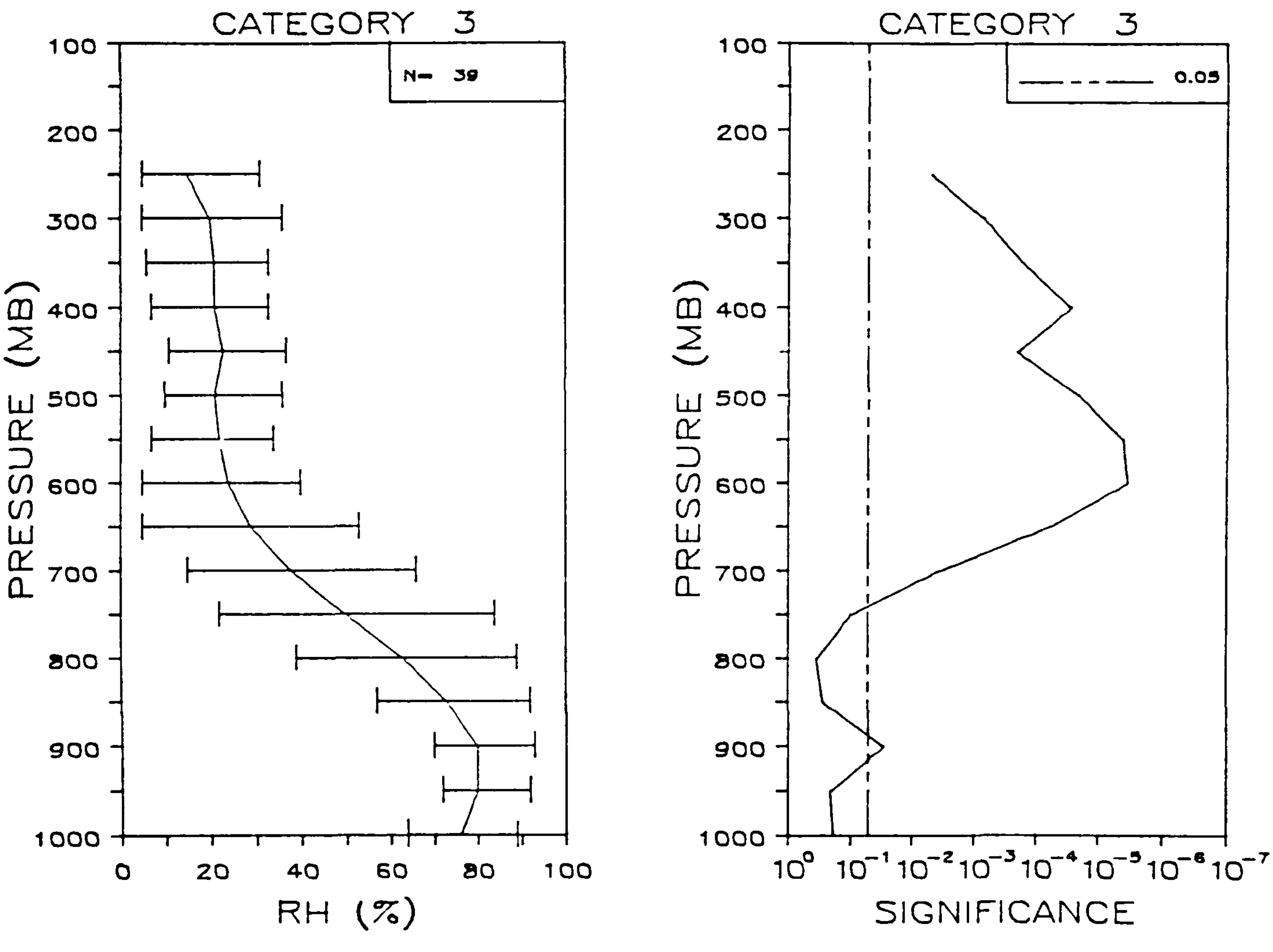

Fig. 5. Same as in Fig. 3 but for Category 3 (stratocumulus).

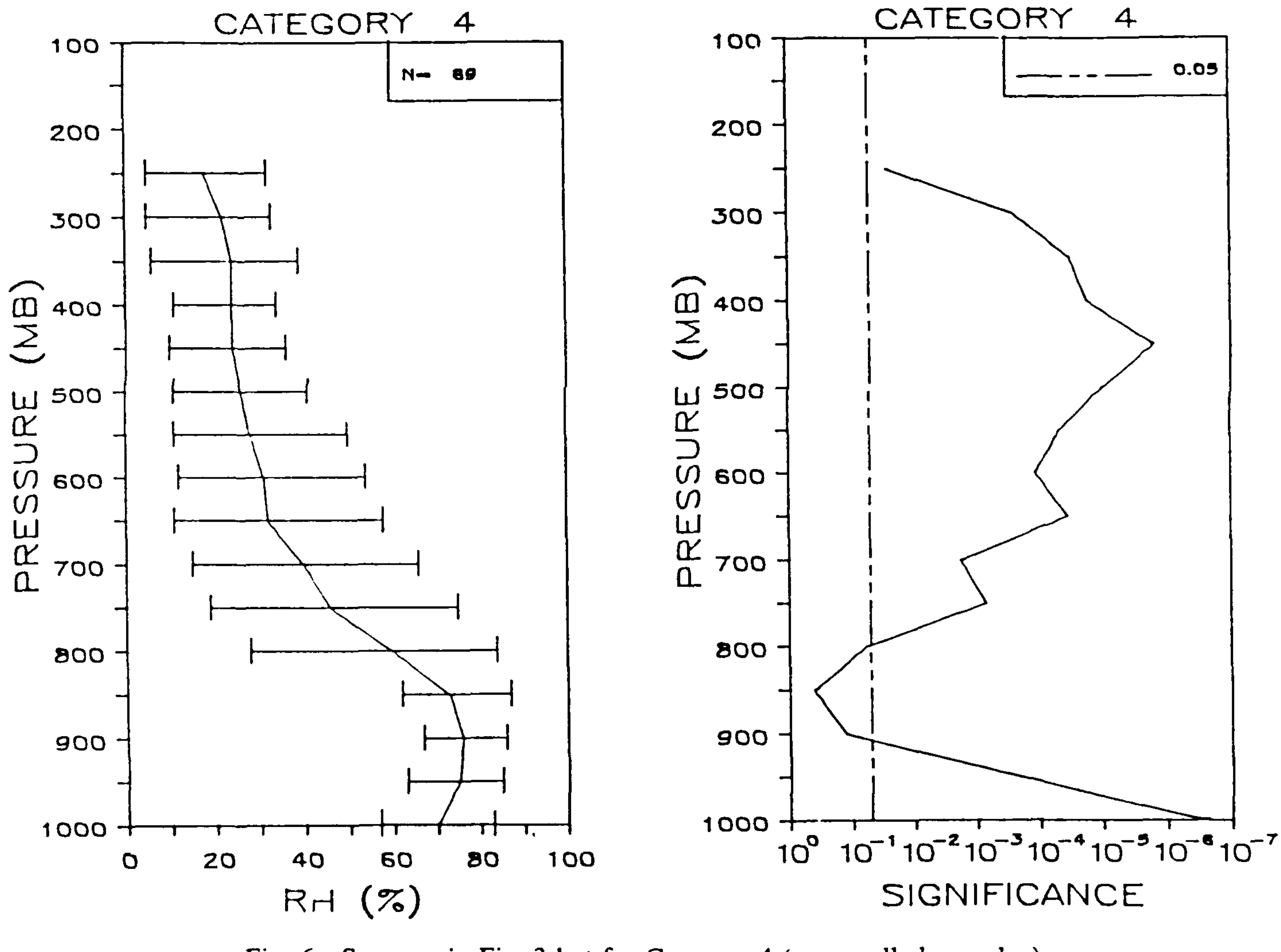

Fig. 6. Same as in Fig. 3 but for Category 4 (open-celled cumulus).

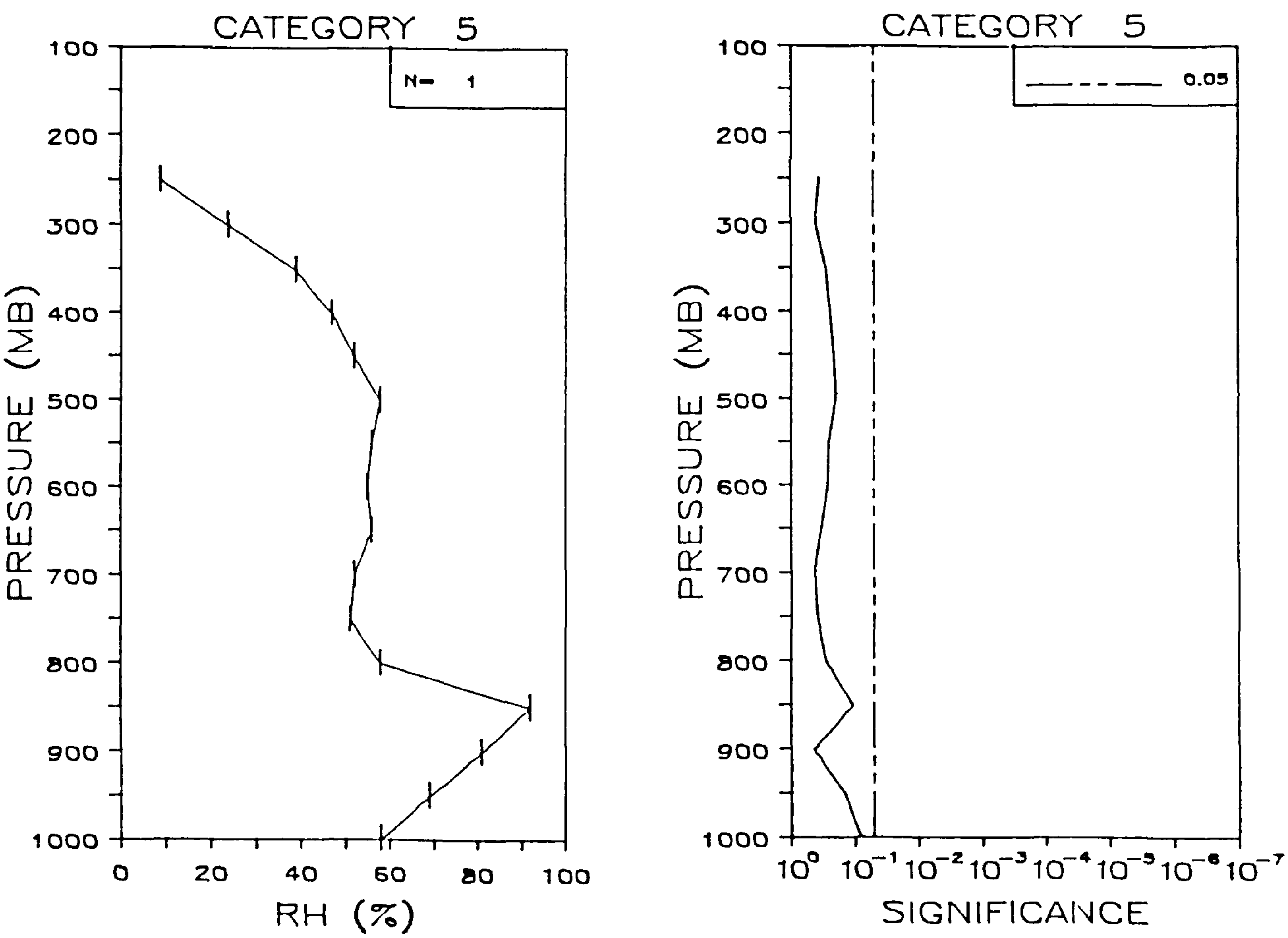

Fig. 7. Same as in Fig. 3 but for Category 5 (open-celled cumulonimbus).

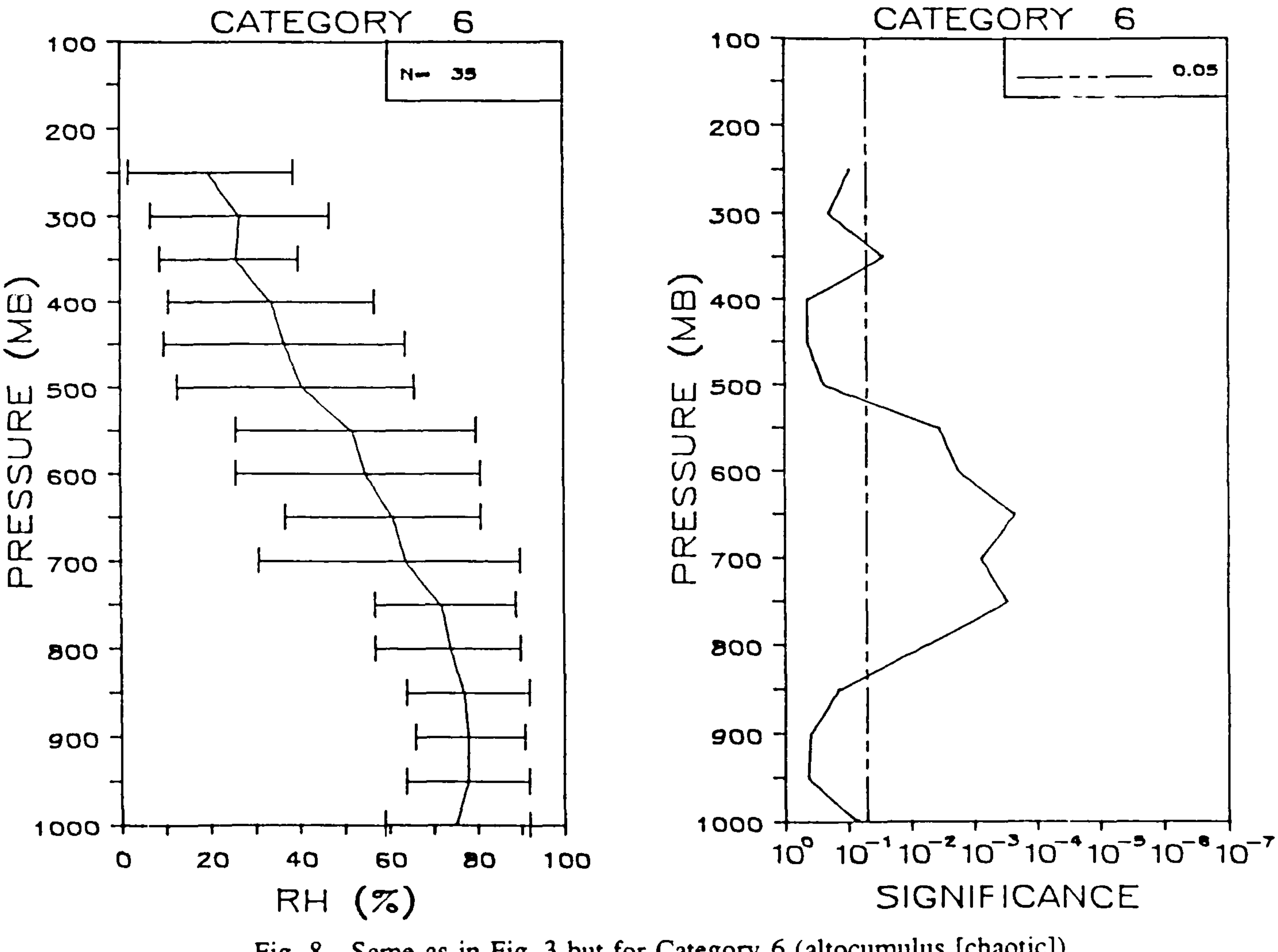

Fig. 8. Same as in Fig. 3 but for Category 6 (altocumulus [chaotic]).

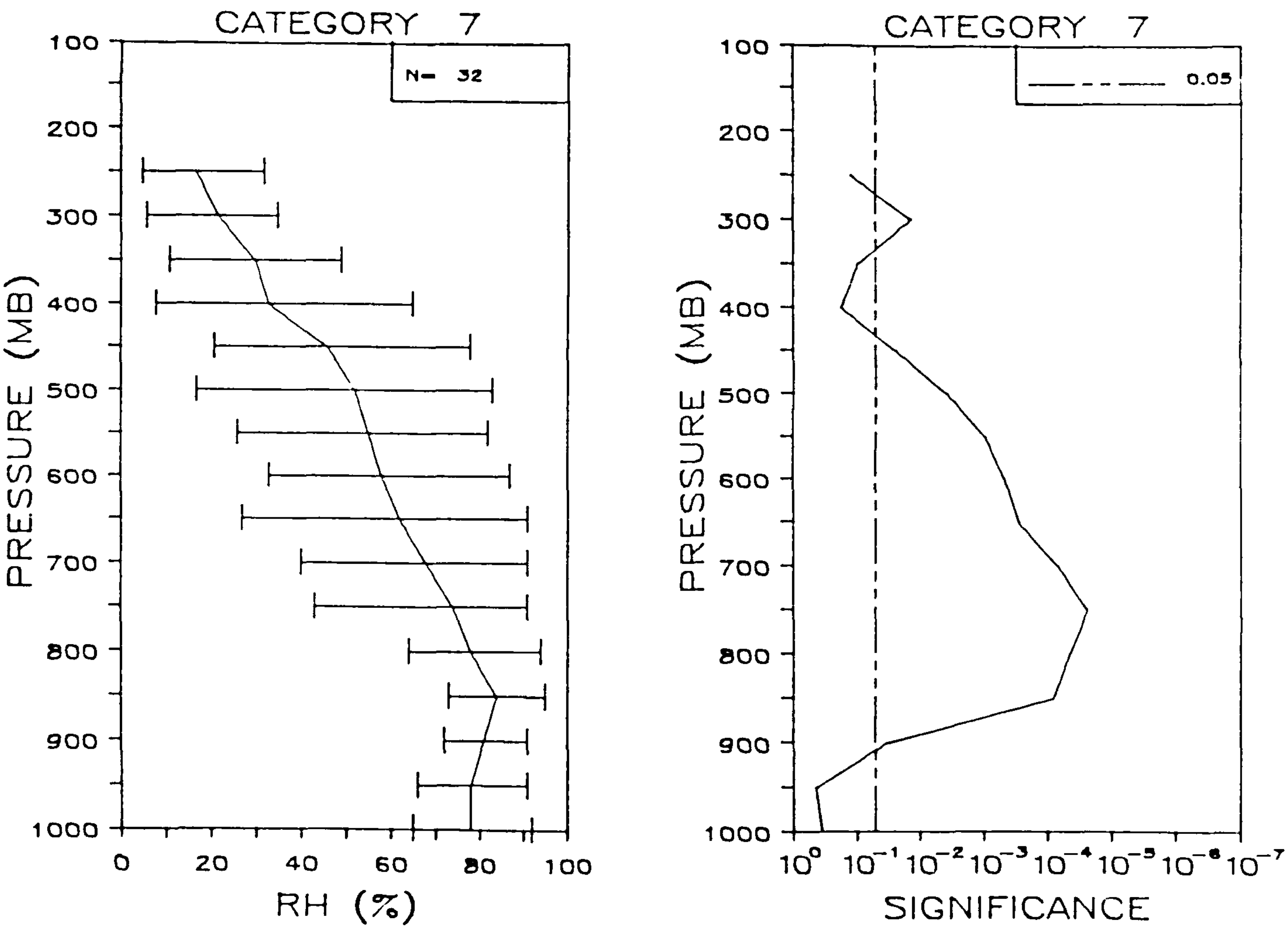

Fig. 9. Same as in Fig. 3 but for Category 7 (altostratus [organized]).

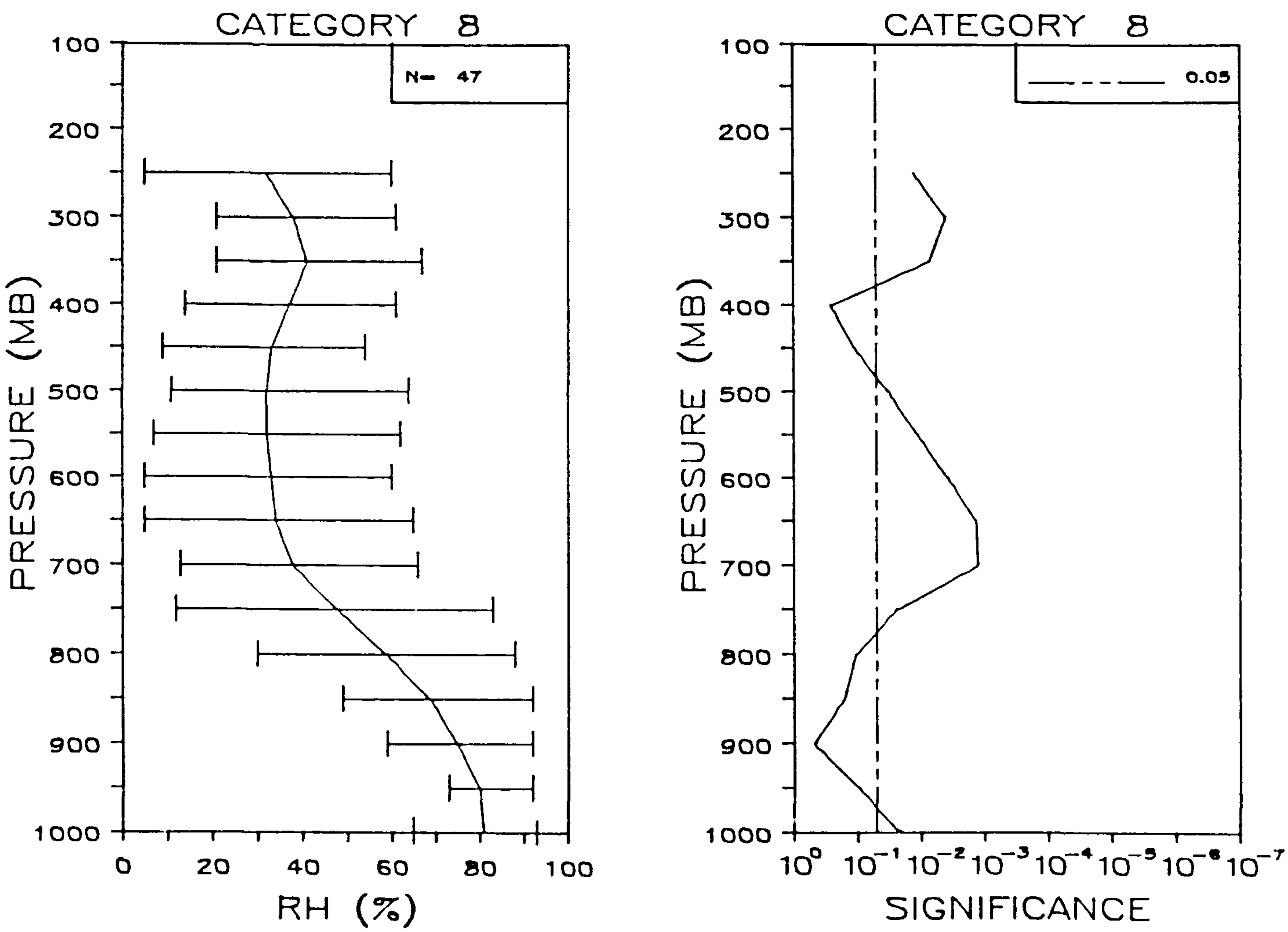

Fig. 10. Same as in Fig. 3 but for Category 8 (thin cirrus).

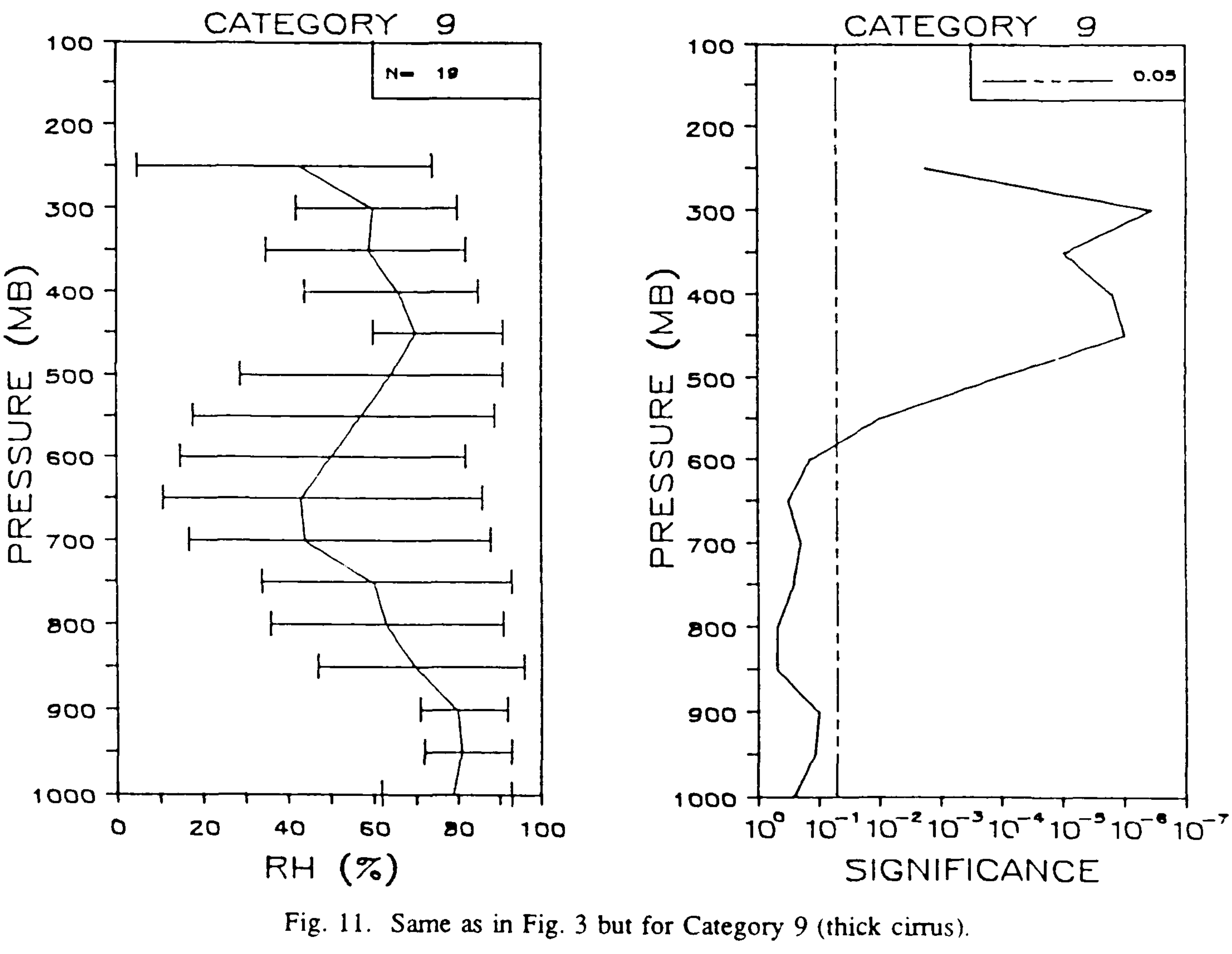

Fig. 11. Same as in Fig. 3 but for Category 9 (thick cirrus).

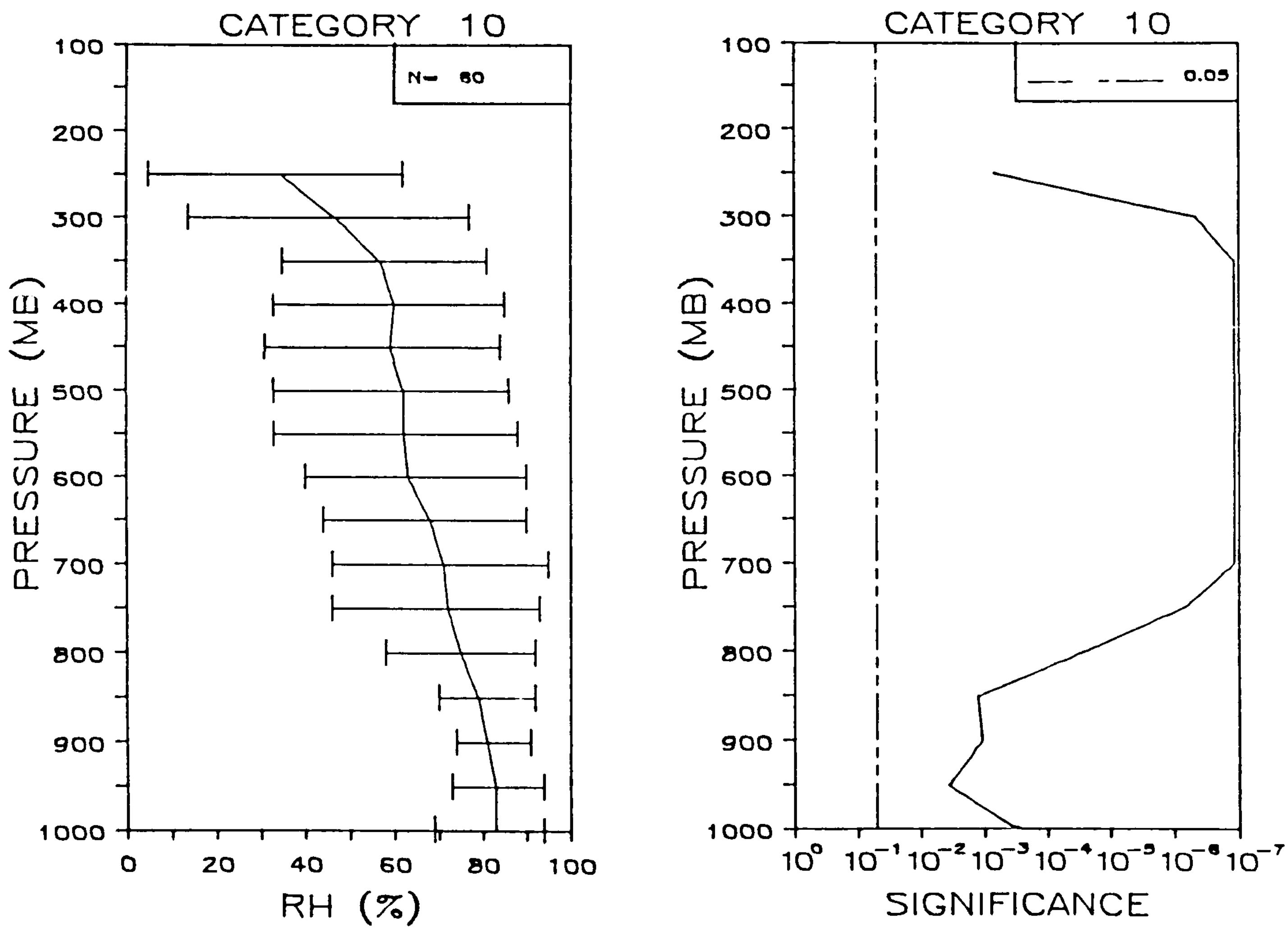

Fig. 12. Same as in Fig. 3 but for Category 10 (chaotic low, mid, and high clouds).

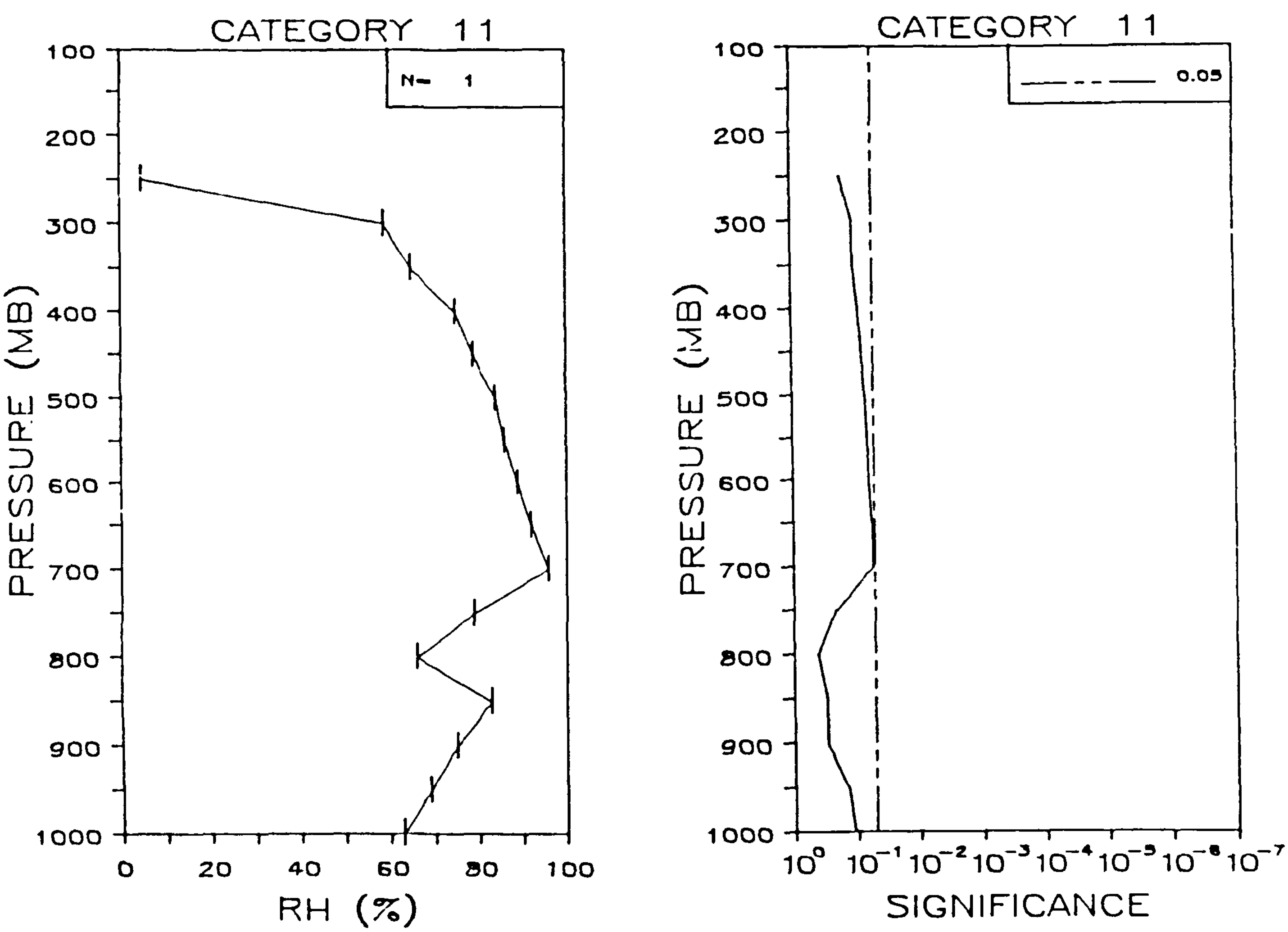

Fig. 13. Same as in Fig. 3 but for Category 11 (organized low, mid, and high clouds).

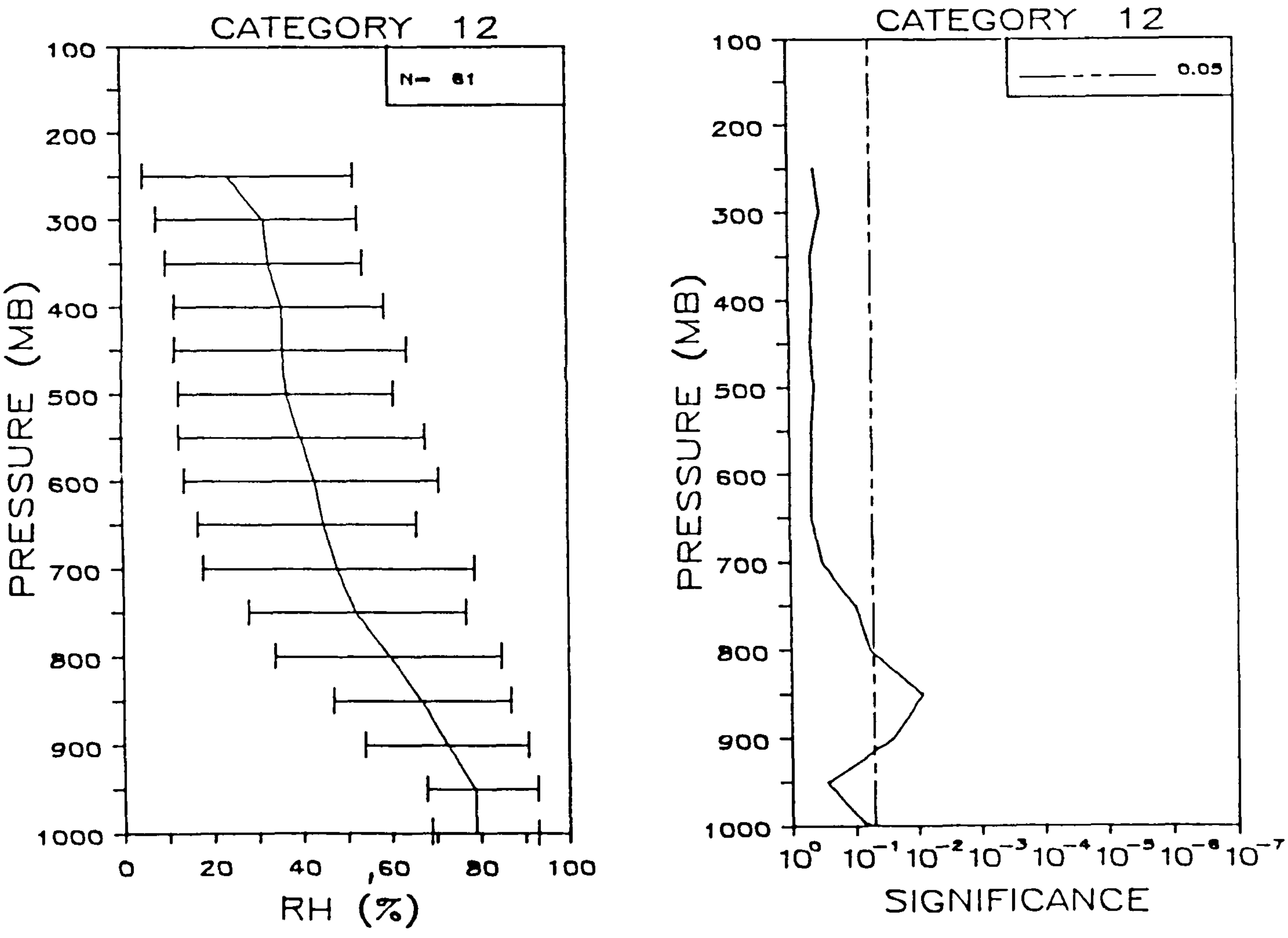

Fig. 14. Same as in Fig. 3 but for Category 12 (undecided).

Table 4. Significance
(Number of levels with 0.05 or better)

	1	2	3	4	5	6	7	8	9	10	11
2	.0435 (9)										
3	.0174 (13)	.1897 (2)									
4	.0461 (5)	.1067 (5)	.1292 (4)								
5	.1487 (0)	.1706 (0)	.1539 (3)	.1809 (0)							
6	.0055 (9)	.0188 (11)	.0073 (9)	.0058 (10)	.2617 (0)						
7	.0025 (10)	.0134 (11)	.0051 (10)	.0015 (12)	.2846 (0)	.1846 (1)					
8	.0428 (9)	.0951 (5)	.0426 (7)	.0403 (7)	.2174 (0)	.0109 (10)	.0033 (12)				
9	.0023 (12)	.0254 (8)	.0059 (8)	.0021 (12)	.2269 (0)	.0157 (8)	.0243 (10)	.0321 (7)			
10	.0001 (16)	.0016 (14)	.0001 (13)	.0001 (16)	.2110 (0)	.0074 (9)	.0307 (5)	.0003 (13)	.1075 (4)		
11	.0786 (9)	.0918 (0)	.1020 (8)	.1075 (7)		.1372 (0)	.1262 (0)	.1174 (3)	.2486 (0)	.2036 (0)	
12	.0431 (8)	.0724 (7)	.0126 (12)	.0121 (11)	.2585 (0)	.0455 (8)	.0130 (10)	.1147 (6)	.0218 (7)	.0001 (7)	.1104 (3)

Poor significance values for categories 5 and 11 are understandable due to their being made up of only one sounding. Excluding comparisons with categories 5 and 11, only 4 out of 45 comparisons had fewer than 5 levels with a significance value worse than 0.05. As was the case in the North Atlantic study, comparisons between category 2 and 3, 6 and 7, 9 and 10, as well as 9 and 11 showed little significance. Similarities between 2 and 3, as well as 6 and 7 are understandable due to their being very similar meteorological condtions. The similarity between 9 and 10 can be attributed to a limitation in the subjective satellite analysis technique in trying to determine the amount of cloudiness below thick cirrus. The results of the comparison between 9 and 11 in this study cannot be considered meaningful due to only one sounding being used to make up category 11.

4. DISCUSSION

As was the case in the North Atlantic study, the relative humidity composites have statistical significance, and qualitatively show physical significance. The problem of no relative humidity values in the composites close to saturation when significant cloud layers are expected, discussed in the North Atlantic study, is also found here. The same explanations for this problem apply here also, with the exception of the problem of low resolution imagery at times other than the sounding times. In this study, high quality visual and infrared satellite imagery within one hour of the sounding time was used.

The explanations for the lack of relative humidity values near saturation when significant cloud layers are expected are: incorrect satellite image analysis, inherent spatial variability of moisture in the atmosphere, and instrument errors in the measurements.

The relative humidity composites computed in this study appear to be similar to those computed in the North Atlantic study. A statistical comparison of the two sets of composites would be needed to establish this apparent similarity.

5. SUMMARY

Vertical moisture profiles for use in satellite bogusing of moisture into numerical weather prediction model initial analyses were presented for the Northwest Pacific region. The profiles were based on a 12 category cloud classification scheme and computed from 409 soundings of relative humidity versus pressure taken from ships in the Northwest Pacific between 1981 and 1987. Assignment of soundings to one of the cloud categories was based on a subjective analysis of visual and infrared satellite imagery taken within one hour of the sounding time. Composites for the categories and results of statisitical significance tests were presented. The composites showed statistical significance and appeared to vary appropriately according to their different descriptions.

As was the case in the North Atlantic, there was a lack of relative humidity values near saturation in the composites where a significant cloud layer would be expected. Subjective satellite image analysis errors, spatial variability of moisture in the atmosphere, and instrument measurement errors were given as possible explanations.

The sounding composites in this study were observed to be similar to those presented in the North Atlantic study. It was suggested that a statistical comparison between the two sets of composites would be needed to establish this observation.

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